Optimal Estimation Retrieval of CO_2 from AIRS spectra

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With thanks to Susan Sund-Kulawik, John Worden, Kevin Bowman, Mike Gunson and Luke Chen

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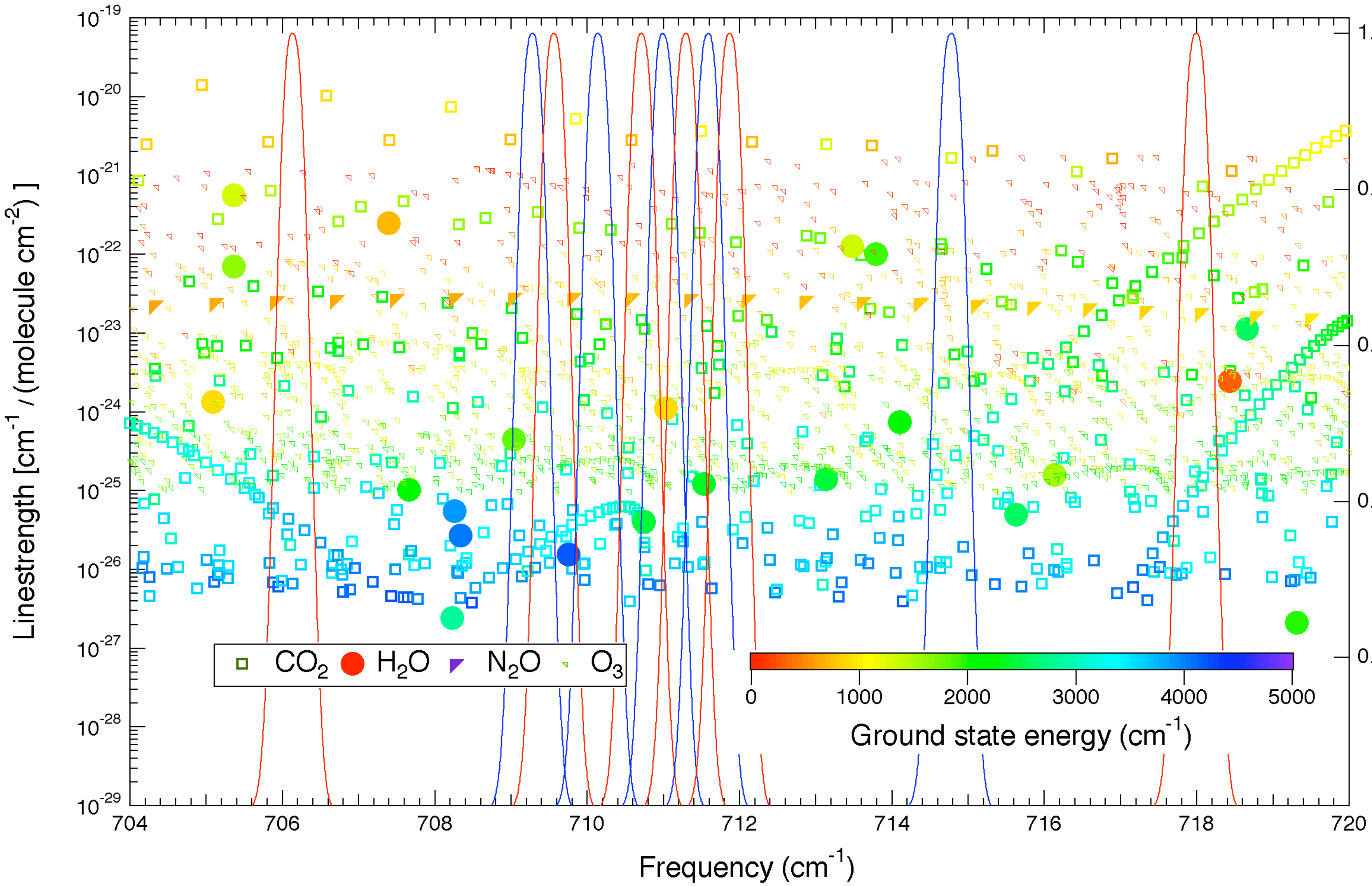
Goals:

- Develop a method using Optimal Estimation (OE) techniques (including constraints) to retrieve upper tropospheric CO_2.
- Compare retrievals with Vanishing Partial Derivatives (VPD) results.
- Emphasis is on *distribution* of results
  - Biases possible between OE and VPD because of different forward models and re-retrieval of temperature and water vapor profiles

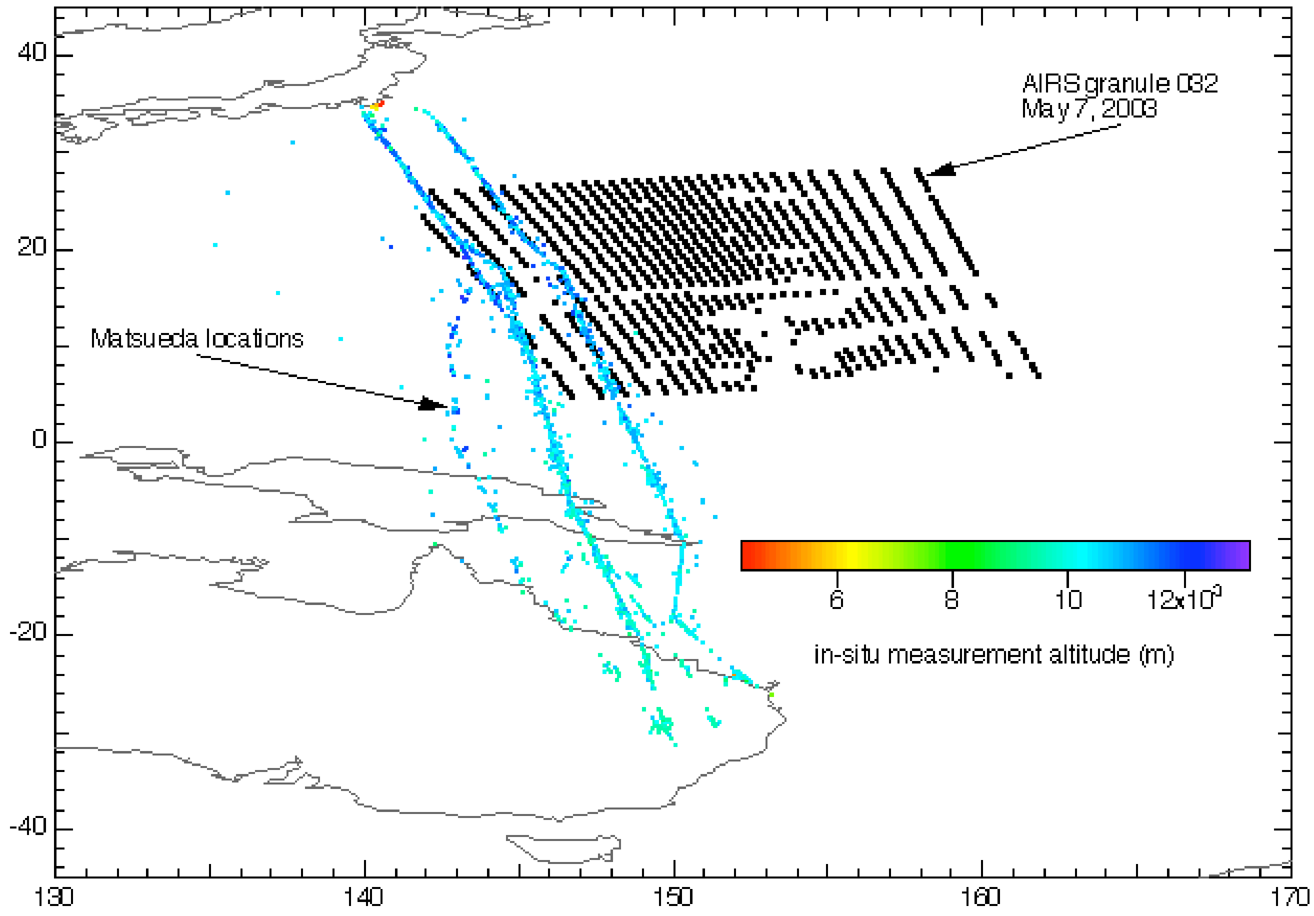
Methodology:

- TES code and forward model.
- AIRS cloud-cleared radiances.
- Temperature and water vapor profiles retrieved prior to CO_2 retrieval.
- Water and ozone simultaneously retrieved as “interferent gases” in CO_2 retrieval.

What’s in the window?



Measurement location



Noisy measurement for AIRS so we need to average results

Optimal Estimation Cost Function

$$
\begin{aligned}
C &= \min_{x}\Big(\big(\mathbf{y}-F(\mathbf{x})\big)\mathbf{S}_n^{-1}\big(\mathbf{y}-F(\mathbf{x})\big)^T + \big(\mathbf{x}-\mathbf{x}_c\big)\boldsymbol{\Lambda}\big(\mathbf{x}-\mathbf{x}_c\big)^T\Big) \\
&= \min_{x}\Big(\left\|\mathbf{y}-F(\mathbf{x})\right\|^2_{\mathbf{S}_n^{-1}} + \left\|\mathbf{x}-\mathbf{x}_c\right\|^2_{\boldsymbol{\Lambda}}\Big)
\end{aligned}
$$

$\hat{x}$ = retrieved state $\quad$ x = true state

x_c = first guess $\quad$ y = observed radiance

$F(x)$ = forward model $\quad$ S_n^{-1} = noise covariance matrix

$\boldsymbol{\Lambda}$ = constraint matrix (usually inverse of a priori covar matrix)

(This ignores mappings used in retrieval scheme.)

Optimal Estimation Cost Function

$$C = \min_{x}\left(\left(\mathbf{y} - F(\mathbf{x})\right)\mathbf{S}_n^{-1}\left(\mathbf{y} - F(\mathbf{x})\right)^T + \left(\mathbf{x} - \mathbf{x}_c\right)\boldsymbol{\Lambda}\left(\mathbf{x} - \mathbf{x}_c\right)^T\right)$$
$$= \min_{x}\left(\left\|\mathbf{y} - F(\mathbf{x})\right\|^2_{\mathbf{S}_n^{-1}} + \left\|\mathbf{x} - \mathbf{x}_c\right\|^2_{\boldsymbol{\Lambda}}\right)$$

$\hat{x}$ = retrieved state — x = true state

x_c = first guess — y = observed radiance

$F(x)$ = forward model — S_n^{-1} = noise covariance matrix

$\boldsymbol{\Lambda}$ = constraint matrix (usually inverse of a priori covar matrix)

What to choose for constraint?

(This ignores mappings used in retrieval scheme.)

An ad hoc covariance/constraint

Note that we're retrieving a *ln*(mixing ratio) profile

On the diagonal:

$$S_{i,i} = \left[\ln\left(\frac{\beta - 0.01}{1 + 0.03(z/\delta z)} + 1.01 \right) \right]^2$$

β is the fractional std. dev. at surface

z = altitude

δz = vertical spacing

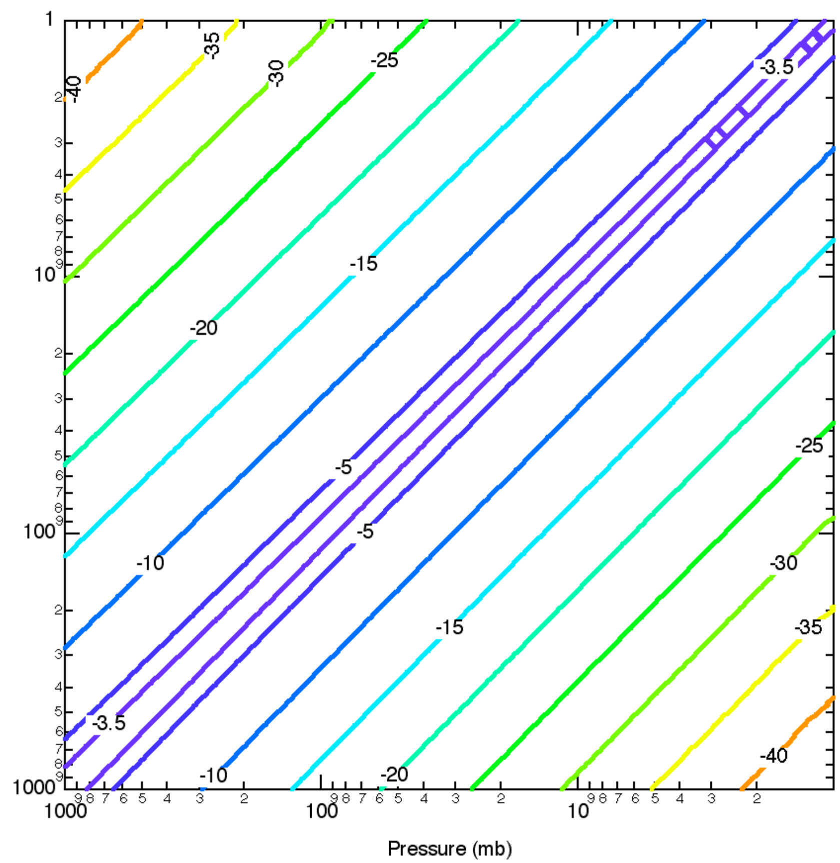
Off diagonals[1]:

$$S_{i,j} = S_{i,i} \exp\left(-|i - j| \frac{\delta z}{h} \right)$$

h = off-diagonal length scale

Individual errors not rigorous because of ad hoc constraint

Log$_{10}$ covariance



$\beta = 0.08$; $h = 0.5$ km

[1]per Rodgers [2000]

Sample Averaging Kernel

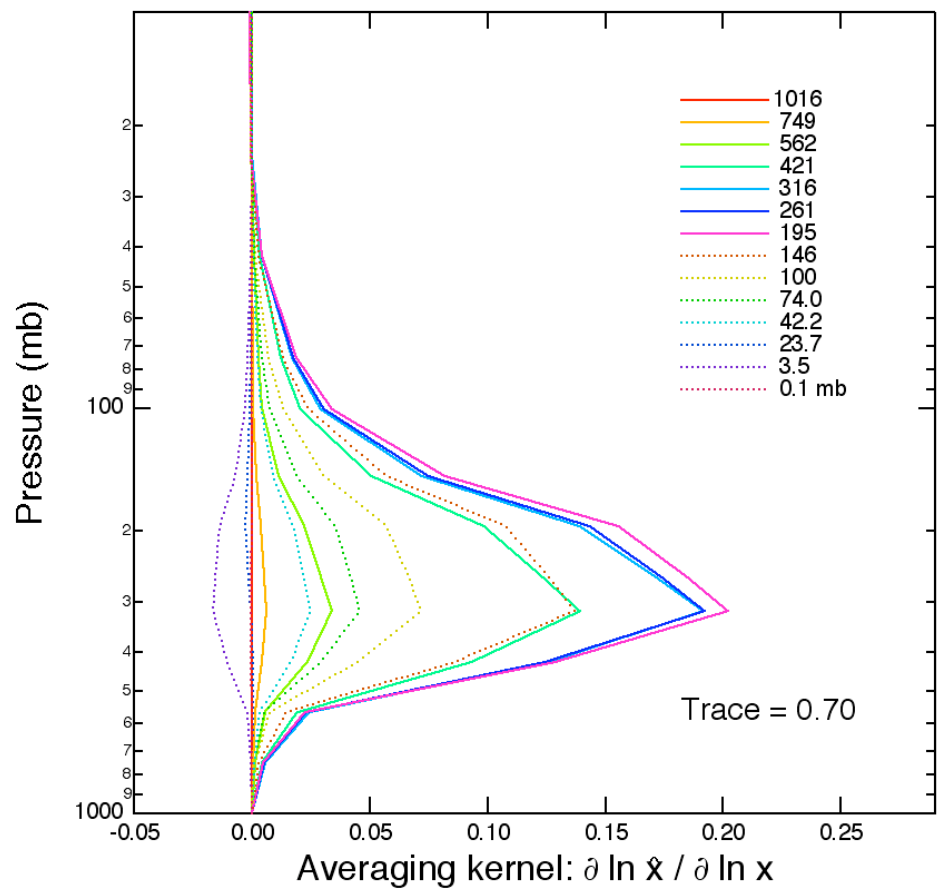
Varies observation to observation

Average channel SNR for this example = 114

Peak sensitivity from ~200 to 400 mb

Diagonal of constraint matrix largely determines sensitivity.

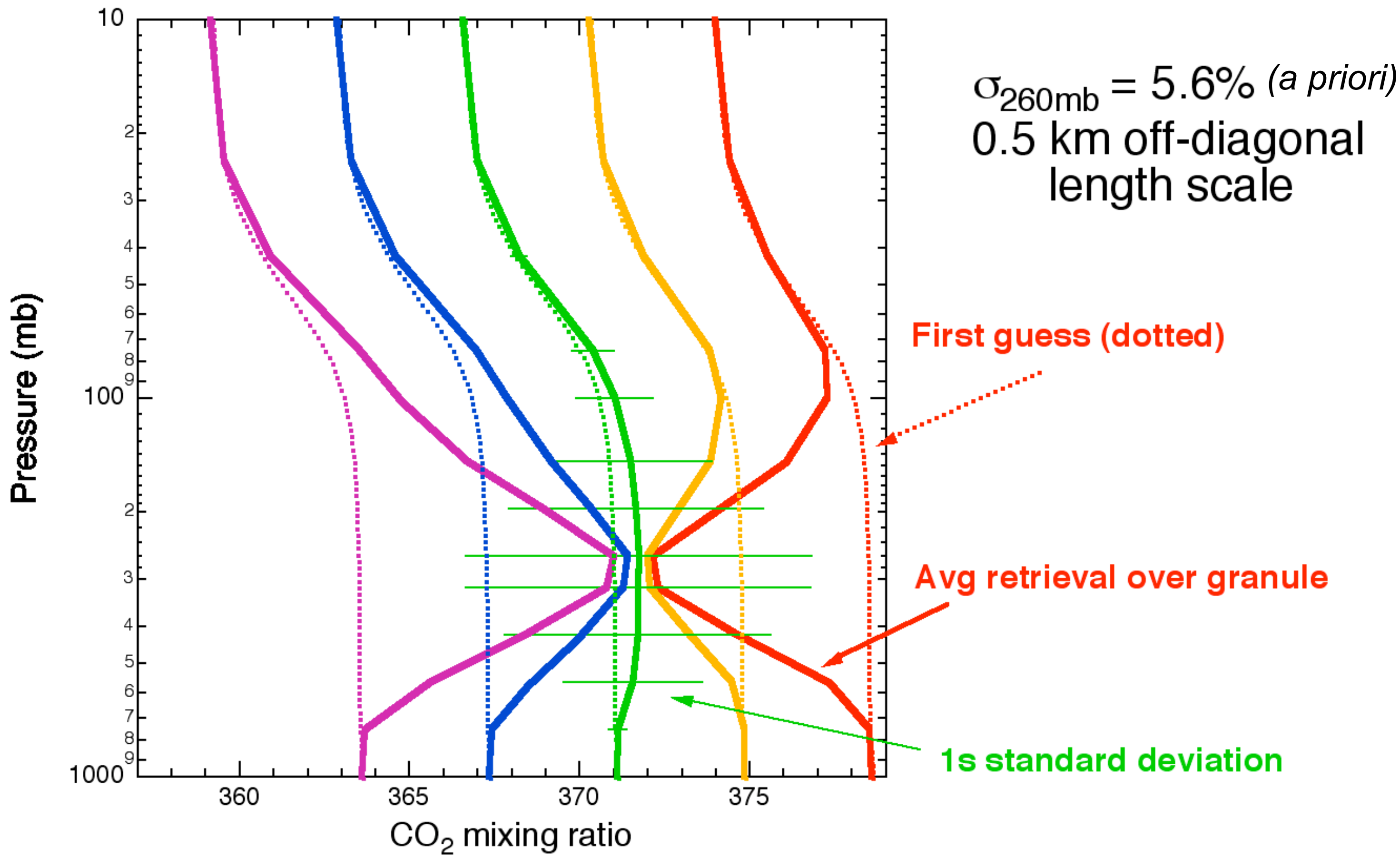
Off-diagonals determine resolution.



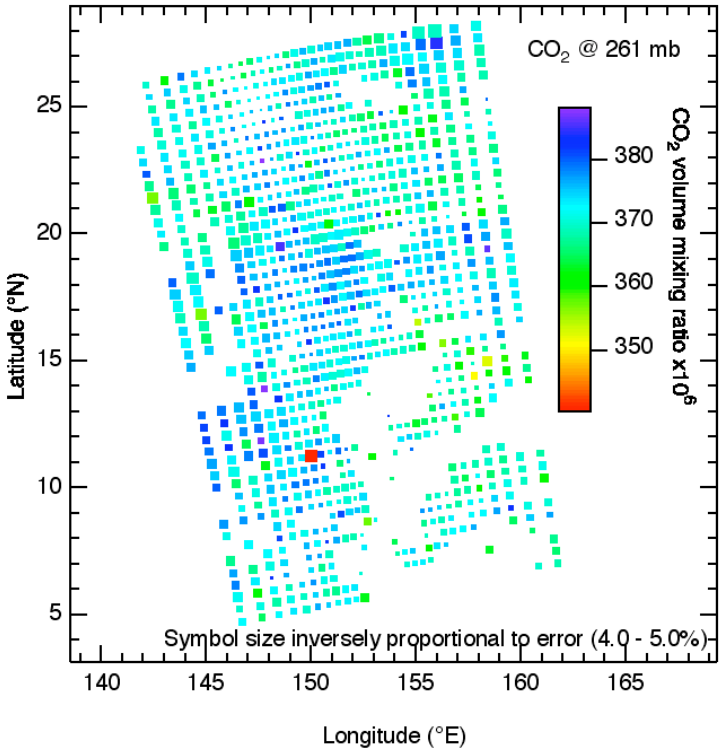
h = 0.5 km, a priori σ_{260mb} = 5.6%

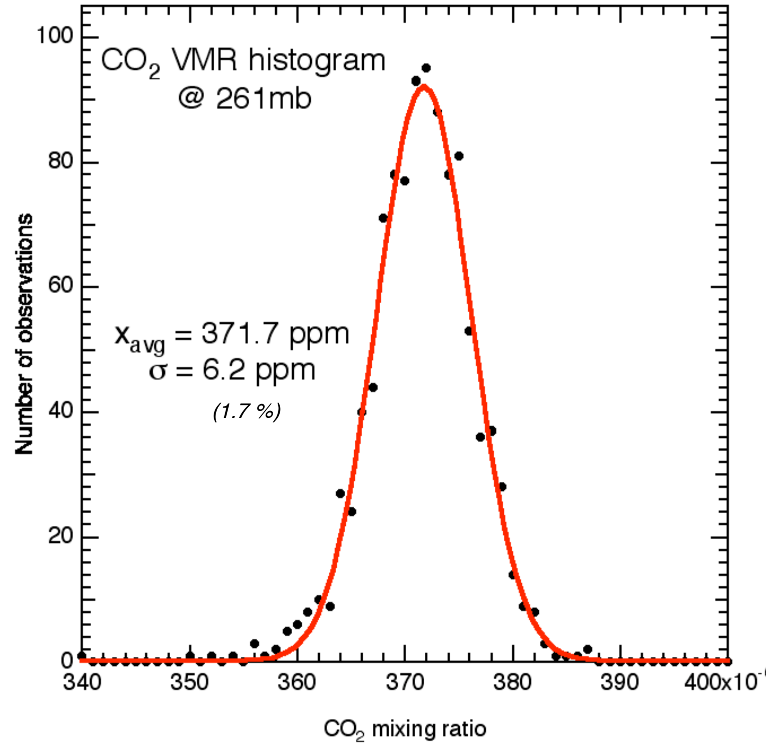
Average retrieval results over granule

Analysis over granule repeated five times using same constraint but different 1st guess profiles

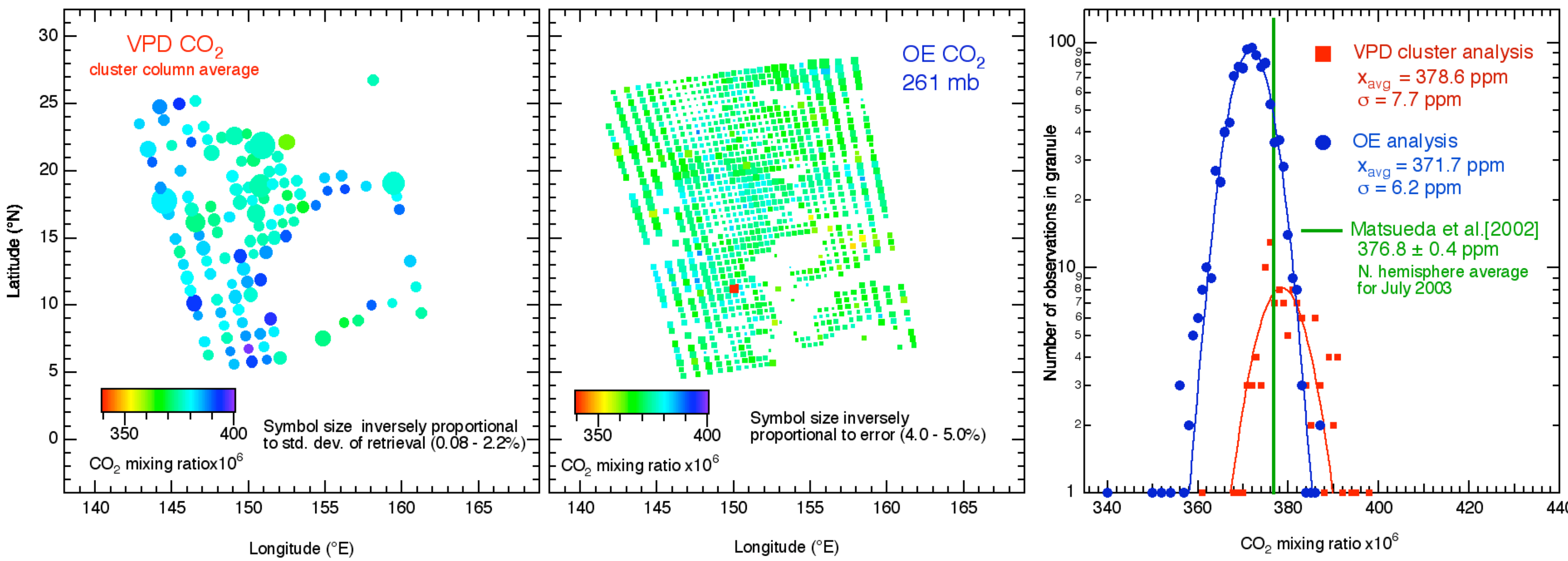


Retrievals over granule @ 261 mb





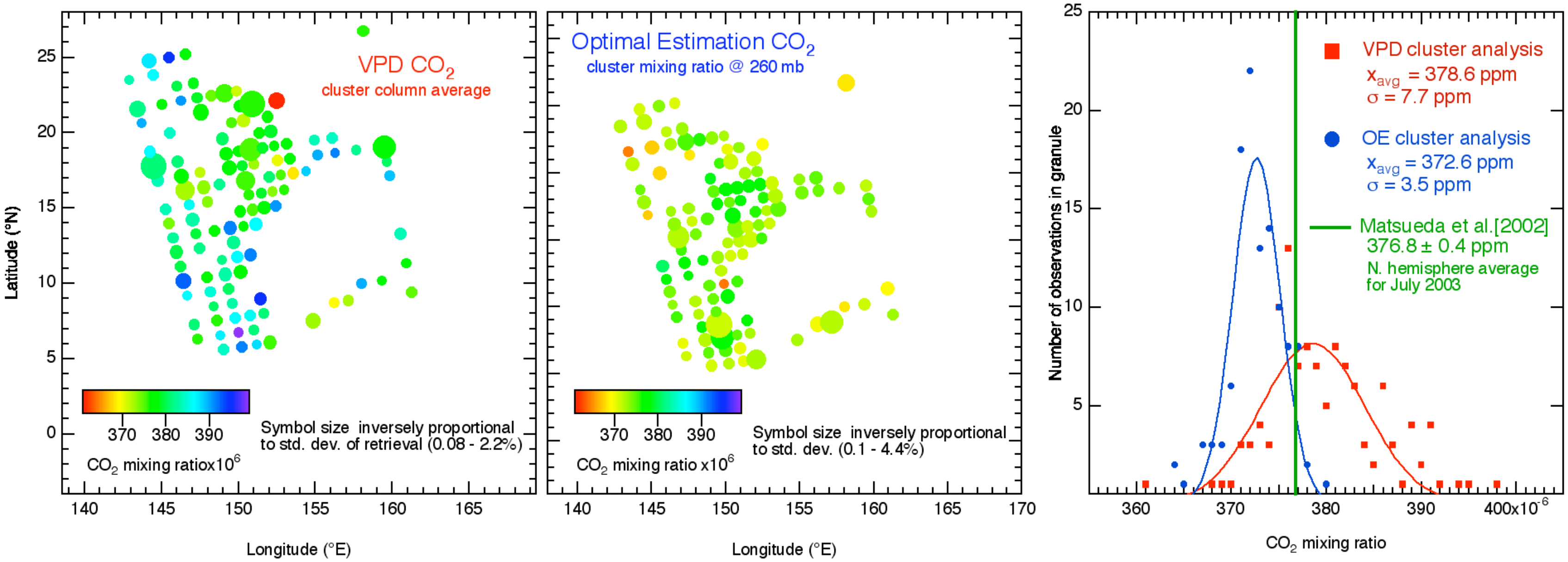
Comparison to Vanishing Partial Derivatives



Thanks to Luke Chen for VPD processing

Clustered comparison to Vanishing Partial Derivatives

Optimal Estimation retrievals filtered and averaged similar to VPD.



Conclusions

- With OE, “loose” diagonal and low off-diagonals in a priori covariance give robust retrievals *in the aggregate*
- Comparable distribution of results to VPD
- Need to understand bias between OE and VPD results
  - Forward model (incl. spectroscopy differences)?
  - Temperature profile?
- Need to merge in AIRS forward model to increase speed of retrieval, and provide data on monthly timescales.

Backup Slides

Repeat the analysis with different covariance matrices

On the diagonal:

$$S_{i,i} = \left[\ln\left(\frac{\beta - 0.01}{1 + 0.03(z/\delta z)} + 1.01 \right) \right]^2$$

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Off diagonals:

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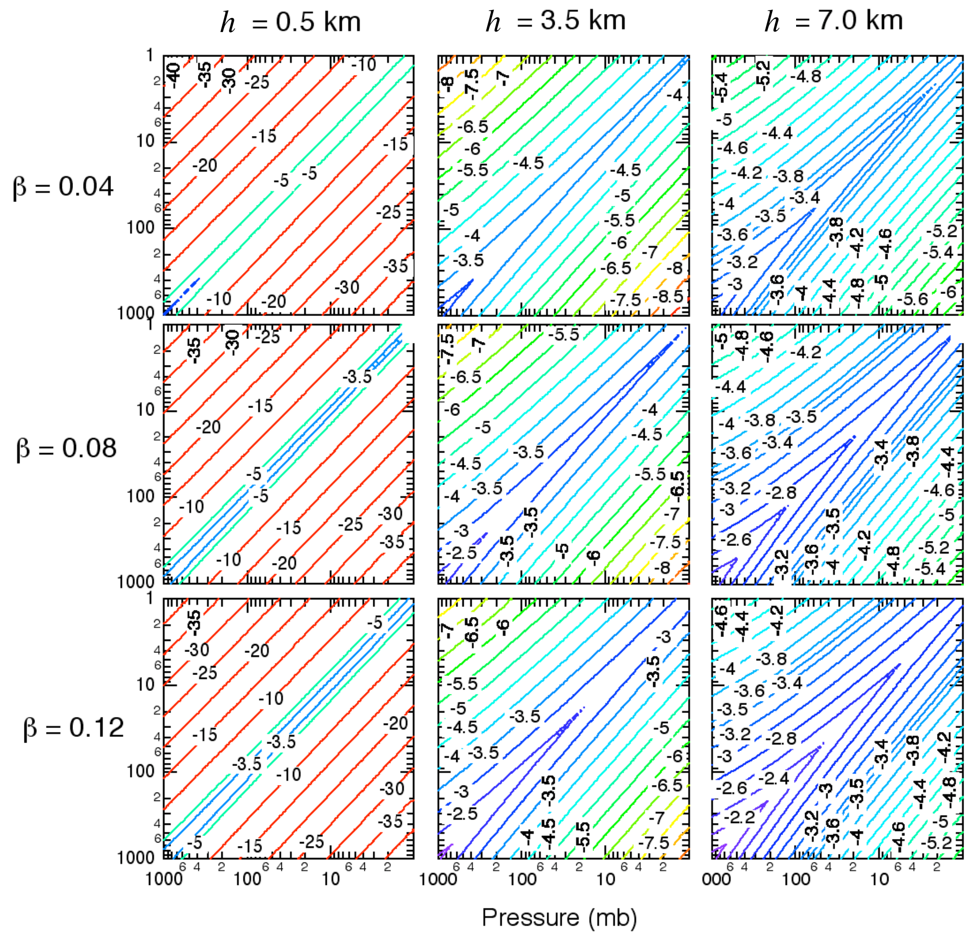
Log$_{10}$ covariance



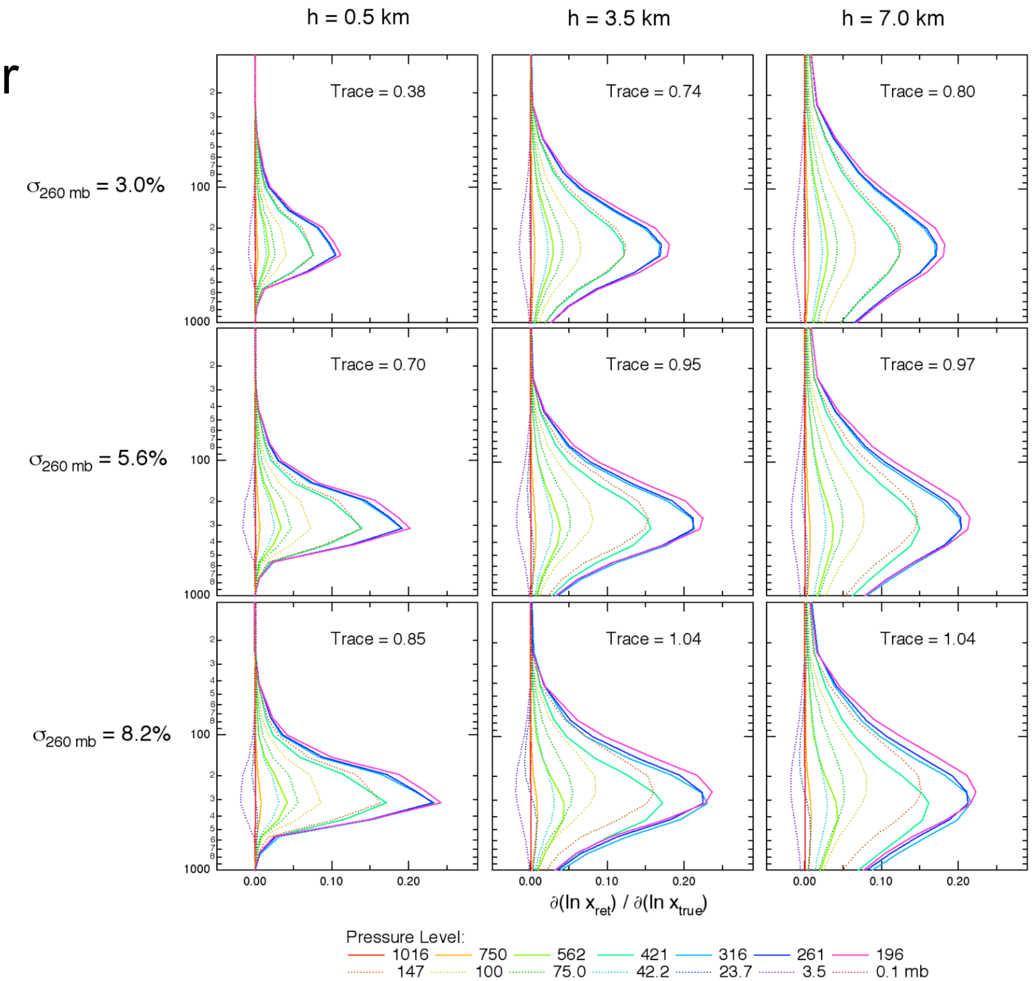
Averaging kernels

Average channel SNR for this example = 114

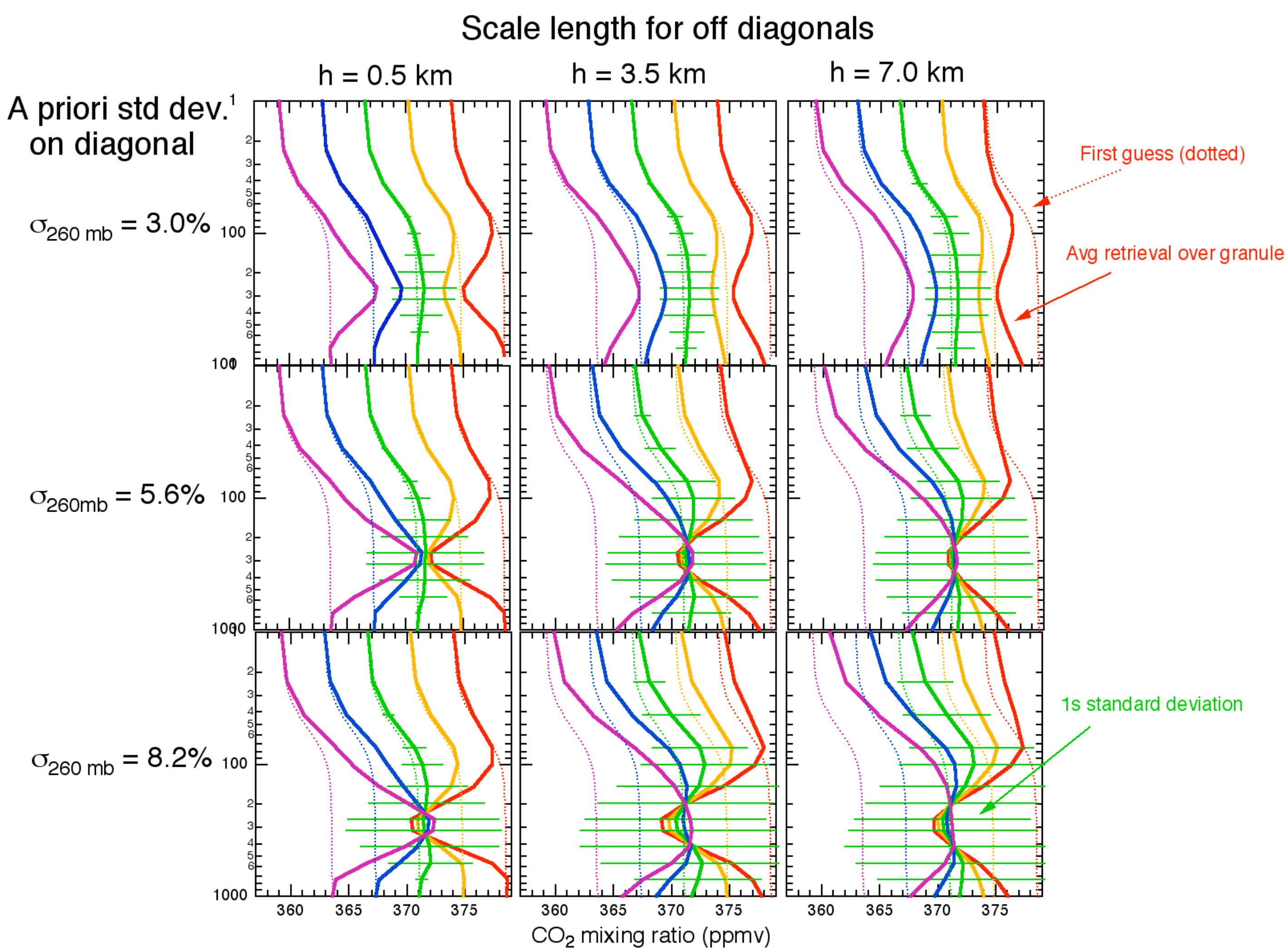
Peak sensitivity from ~200 to 400 mb

Diagonal of constraint matrix largely determines sensitivity.

Off-diagonals determine resolution.



Averaged results (all covar matrices)

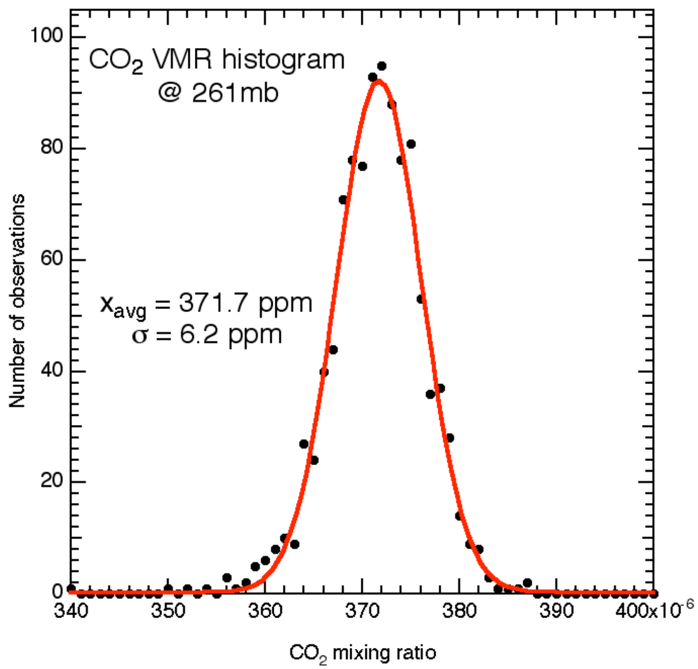


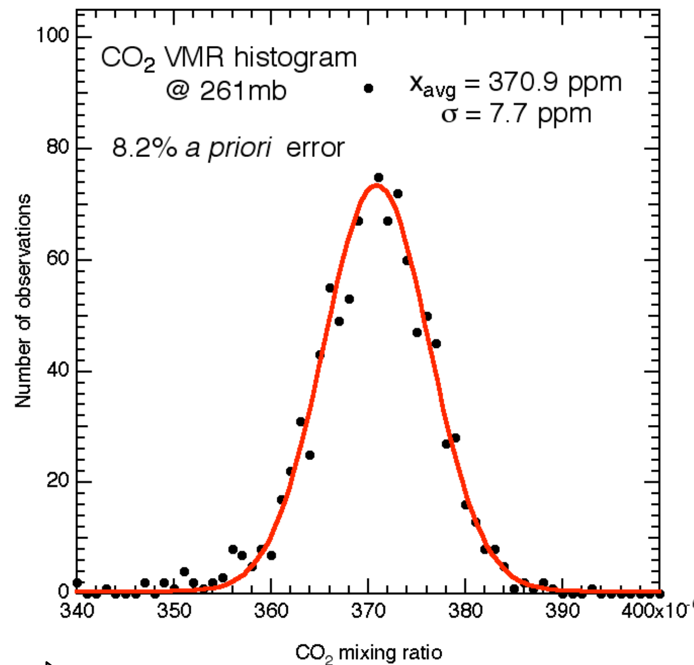
Effect of "looser" constraint

5.6% *a priori* error at 260 mb

46% increase

8.2% *a priori* error at 260 mb





σ = 1.7% → 24% increase → σ = 2.1%

No correlation between VPD and OE cluster results